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RESEARCH ARTICLE

The Effect of Carbon Accounting and Pricing on a Discounted Cash Flow-Based Investment Decision in Real Estate

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Abstract

The real estate sector must transition towards a low-carbon economy. In current investment decisions, carbon emissions are insufficiently considered and may not contribute to a low-carbon portfolio aligned with the sector's target. Therefore, investors require a change in the current DCF model-based investment decision to direct capital to projects that support this goal.

This paper examines the impact of carbon accounting and pricing on a standard investment model using the Discounted Cash Flow (DCF) model. Three additional cash flows are modelled, representing the Embodied Carbon Cost (ECC), Operational Carbon Cost (OCC), and Maintenance Carbon Cost (MCC). This paper introduces a novel application of carbon pricing in real estate investment, accounting for embodied, operational, and maintenance-related emissions during the use phase, which results in a practical framework and guide for practitioners.

The Carbon Price needs to be sufficiently high to make an impact and contribute to excluding energy-inefficient assets as an investment opportunity. Furthermore, the influence of ECC is minor compared to OCC, making carbon pricing for ECC less relevant in investment decisions. Ultimately, the MCC is a significant factor to consider when making an investment decision.

Carbon pricing can encourage the use of circular and biobased materials, reducing emissions during the construction, renovation, and use phases. Investors should apply a carbon price to affect investment decisions by excluding carbon-intensive assets from investment portfolios. Investors could align their capital with the sector's low-carbon goal by including monetised carbon emissions in an investment decision.

Keywords Real Estate · Sustainable · Investment Decision · Discounted Cash Flow · Carbon Pricing · Carbon Costs.

1. Introduction

1.1. The Importance of Carbon

Carbon emissions are a major contributor to global warming. The construction sector is responsible for 37% of the world's process and energy-related carbon emissions, which continue to increase yearly (IEA, 2022). Therefore, the real estate sector will play a crucial role in achieving a climate-neutral Europe by 2050, as agreed upon in the EU Green Deal (EU, 2019).

To achieve the ambition of climate neutrality, the EU Framework on Sustainable Finance (2021) aims to steer invested capital toward the goals set in the Green Deal. Real estate investment funds in the EU

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held approximately €952 billion in assets as of 2022, with roughly 80% owned by institutional investors, including pension funds and insurers (Resti, 2025). Furthermore, investments in real estate are decisions with long-term consequences due to the building's lifetime. Therefore, it is essential to steer capital flows of institutional investors in the right direction. Carbon accounting can help institutional investors make informed investment decisions.

Investors often use carbon accounting to report compliance with regulatory requirements. Pricing the carbon in a financial investment decision can be the next step. Sentiment is beginning to shift, but the use of a carbon price by real estate investors remains relatively low. This is due to the lack of a uniform approach, the complex relationship between embodied and operational carbon, and the fragmentation between different stakeholders in the construction and investment sectors, which makes it difficult to keep an overview of carbon flows (Varriale, 2023). Investors need to take the first step because property valuers are unable to include decarbonisation costs, as they are currently out of scope in standards such as IVSC, TEGOVA, and RICS (Jongen, 2021).

To accelerate this transition, it may be helpful to develop a better understanding through the practical application of a carbon price in decision-making and to gain insight into the impact of carbon during the construction and use phases.

Using an internal carbon price, carbon accounting can evaluate an investment decision in real estate (Hazaea et al., 2023). That way, carbon accounting becomes a strategic tool in transitioning towards a low-carbon economy. Carbon pricing policies mitigate investment-related carbon risks, incentivise low-carbon development, and enhance long-term growth and profitability prospects within the sector. Elevated carbon taxes have led investors to more rigorously evaluate risk exposure, with increased attention to emerging environmental and regulatory risks (Hu, 2024). The effect may be the same at both portfolio and asset levels. Carbon constraints alter the behaviour of property developers, steering them towards emission reduction (Yao et al., 2023).

When carbon emissions are included in an investment decision using a carbon price, institutional investors can influence the materials used in new developments and renovations. A lower return for high-carbon assets, achieved by introducing an additional cash flow for carbon emissions into the valuation model, directs capital towards low-carbon assets.

This paper aims to evaluate an investment decision based on a Discounted Cash Flow (DCF) model, which incorporates additional cash flows related to carbon emissions during the building's construction and operational phases. Decision-making, focusing on the financial appraisal valuation methodology, to proceed with a real estate acquisition, disregarding all other parameters that may influence the decision-making process. In the remainder of this paper, this is limited to DCF model-based appraisal for internal decision-making by institutional investors.

The contribution of this paper lies in its novel application of carbon pricing within real estate investment analysis, incorporating not only embodied and operational carbon but also the carbon emissions associated with maintenance throughout the use phase. This is particularly relevant for institutional investors, who have a major influence on the transition and are characterised by a long investment horizon. This results in a practical framework and guide for practitioners.

1.2. Embodied, Operational, and Maintenance Carbon

Of the total sector emissions, 10% are generated by the production of building materials, such as cement, iron, and steel. The emissions captured in the building materials are called Embodied Carbon (EC) (Adams et al., 2019). The remaining 27% of carbon emissions in the construction sector are referred to as Operational Carbon (OC). A European Standard EN 15978:2011, used for Life Cycle Assessments of new and existing buildings, classifies different environmental impacts during a building lifecycle (EN, 2011). The EC emitted during the Production and Construction stage in a Building Life Cycle is categorised as Module A. Emissions during the building's Use phase are categorised as Module B.

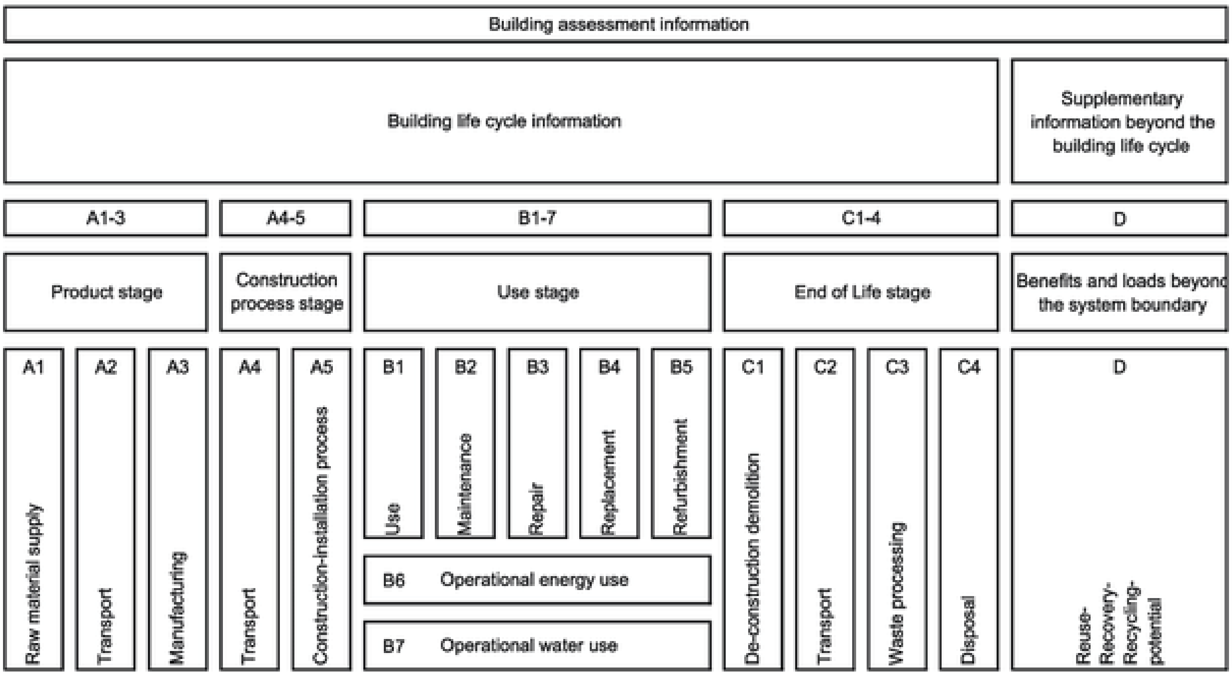

Figure 1 Overview of life cycle stages according to EN 15978:2011 (EN, 2011)

Thanks to advances in reducing OC, recent data from the World Green Building Council indicate that EC is becoming a more significant portion of a building's overall carbon footprint (Rowland et al., 2023). In a business-as-usual model, EC is expected to account for nearly 50% of the overall carbon footprint of new constructions by 2050. However, the real estate sector is not yet aligned with the decarbonisation pathways towards a low-carbon economy and is searching for tools to invest capital with impact. Making the right investment decisions in assets today is vital because buildings will last longer than 2050. It is unclear whether applying carbon accounting and pricing in individual investment decisions effectively achieves a low-carbon portfolio. Furthermore, it is unclear whether it aligns the sector with the path to a low-carbon economy (Morrison & Phillips, 2023). Integrating sustainability into property assessment remains a topic of great interest (Ott & Hahn, 2018).

1.3. Investment Decision-making Based on a DCF Model

The DCF model is an industry-standard valuation model using an income approach to establish the value of an asset (Baum, 2022; Crosby, 2023; Geltner et al., 2014). In addition to the DCF-based approach, investors also use other valuation techniques. In practice, other criteria will also be taken into account (Baum, 2022; Geltner et al., 2014). Despite its widespread use, the DCF model has several limitations, which are briefly described below.

DCF models offer only a limited view of uncertainty. While the discount rate is intended to reflect project risk, it oversimplifies the analysis by using a single rate despite the presence of multiple risk factors. It also fails to address the asymmetry of risk, as investors typically care more about downside than upside. Additionally, DCF overlooks the flexibility that investors must adapt to over time, which can significantly impact future cash flows. (Leung, 2014)

Furthermore, the DCF model is indicated as a potential barrier for sustainable investment because it favours short-term return instead of long-term risk aversion or action (Warren-Myers et al., 2020). The use of the DCF model has also been criticised because the added value of sustainability is not sufficiently considered due to a lack of market evidence (Kucharska-Stasiak & Olbińska, 2018; Myers et al., 2007). Despite these limitations, DCF remains widely understood and used in the real estate industry.

An important reason for adjusting the established DCF model is investor acceptance. A transition will likely succeed by adapting an existing tool that investors already use, rather than expecting a system change. Real estate professionals often hesitate to adopt new techniques beyond their expertise, especially when swift changes are required to steer capital towards low-carbon assets (Damodaran, 2012). Due to increasing material scarcity and expected higher material costs due to ETS-2, an acceleration of the transition is necessary. (Boute, 2023)

This paper examines whether carbon pricing is a viable approach for directing capital towards low-carbon assets by modelling a standard investment decision and varying cash flows for different carbon emissions.

The remainder of the paper focuses on the relevance of carbon accounting and how it can be effectively incorporated into decision-making through pricing mechanisms. A sample asset is used to simulate the financial impact of carbon pricing on the DCF model. The results of the various analyses are then presented and discussed, concluding with conclusions and recommendations for investors.

2. Literature Review

2.1. Carbon Accounting

Carbon accounting measures, reports, and allocates greenhouse gas emissions from human activities. It plays a crucial role in decision-making to mitigate climate change and manage resources responsibly from a carbon emission perspective (Kaur et al., 2023). Despite its widespread use, there is no consistent definition, leading to diverse interpretations and applications across different levels, such as national, project, organisational, and product levels (Hazaea et al., 2023; Stechemesser & Guenther, 2012). The lack of a standardised framework complicates integrating carbon accounting into manufacturing systems and supply chains (Kaur et al., 2024).

Standards for Carbon Accounting vary widely, with different protocols and data sources leading to incomparable results (Chen et al., 2019). The current systems often lack transparency, reliability, and comparability, which hinders effective monitoring and decision-making (Marlowe & Clarke, 2022). Moreover, the variety of accounting methods and regional approaches can prevent the adoption of optimal global solutions, emphasising the need for a unified framework (McDonald et al., 2024).

The field of carbon accounting has evolved significantly over the past decades, from traditional accounting practices to including environmental, social, and governance data. Research has shown a notable increase in studies, particularly in the UK, Australia, and China, highlighting the growing importance of carbon accounting in these regions (Hazaea et al., 2023). The development of carbon accounting is characterised by a shift from counting emissions to integrating them into accounting frameworks. Despite this trend, from an accountability perspective, the potential of carbon accounting remains underexplored (Kiswanto et al., 2023).

Carbon accounting influences corporate decision-making by supporting carbon management strategies (Marlowe & Clarke, 2022). It helps organisations comply with regulations, optimise energy and material flows, and enhance eco-efficiency and product innovation. Integrating carbon accounting into corporate functions such as production, supply chain management, and marketing is crucial for sustainable improvements (Gibassier & Schaltegger, 2015; Schaltegger & Csutora, 2012). However, as indicated above, the lack of standardisation and uniformity in carbon accounting poses a challenge for integrating into manufacturing systems and supply chains (Kaur et al., 2024).

In the context of building design and management, carbon accounting can influence decisions by providing insights into the embodied carbon associated with the construction of a building and the operational carbon linked to the operations of a building. Although not mandatory, carbon accounting can improve decision-making credibility in building projects (Wong et al., 2019). Carbon accounting is integral to strategic management, particularly in carbon trading, investment in low-emission technologies, and regulatory compliance. It provides the necessary information for informed decision-making, helping businesses and consumers make a balanced trade-off for long-term sustainability (Ratnatunga, 2008).

More research is needed to link greenhouse gas inventories to decision-making and reporting systems (Marlowe & Clarke, 2022). This research paper provides the first insight into how institutional investors consider carbon in their investment decisions.

The literature describes different standards used in carbon accounting. The following sections describe the GHG Protocol and the upcoming Value Chain Approach accounting.

2.2. Global GHG Accounting and Reporting Standard

The most widely used standard is the Global GHG Accounting and Reporting Standard, a product of the Partnership for Carbon Accounting and Financials (PCAF). PCAF also published a report in 2020 titled "The Global GHG Accounting & Reporting Standard for the Financial Industry" (PCAF, 2022). This document outlines a detailed approach for calculating "financed emissions" across six asset classes under the Scope 3 Standard. Scope 3 refers to indirect emissions from the value chain, whereas Scope 1 entails direct emissions, and Scope 2 refers to indirect emissions from energy use.

The PCAF Standard for commercial real estate focuses solely on Scope 1 and 2, disregarding embodied carbon until more accurate measurement methods are developed (PCAF, 2022). Financed Emissions are calculated with a sector-specific Attribution Factor. For real estate, the Attribution Factor is calculated by dividing the current property value by the property value at origination, using a weighted average. This Attribution Factor is then multiplied by the building emissions (distinguished between scope 2 and scope 3), which is subsequently based on the energy usage of a building multiplied by the Emission Factor. In an annual report, the development of the total value of a portfolio and its financed emissions provides insight into its sustainable performance. Expressing financed emissions as a relative carbon footprint of the portfolio as $tCO2_e$/€M.

For real estate, embodied and operational carbon are often distinguished. The embodied carbon of a built asset is based on an LCA calculation following EN15978 A, B, and C (Figure 1). The upstream carbon in Module A is considered a sunk cost, as it is locked into the asset. The only reporting obligation for investors is the Downstream carbon emissions in module B6 Energy Consumption (Landry, 2023). This results in a limited understanding of the total carbon emissions associated with real estate investment. Furthermore, the Scope 3 emissions are challenging to estimate consistently and are therefore often underreported. The collection of upstream and downstream emissions data remains a major barrier to achieving transparent and comprehensive disclosure (Comello et al., 2023).

Since 2001, the GHG Protocol has been subject to additions and modifications to develop a functioning accounting method, resulting in a suboptimal system. Therefore, several gaps persist despite the 2020 update (Roston et al., 2023). Another critique on the GHG Protocol arises from the divergence between underlying measurement frameworks: lifecycle assessment (LCA)-based methodologies used for greenhouse gas inventories (GHGI) and double-entry bookkeeping systems employed in financial reporting (Jia et al., 2023).

2.3. Value-chain Approach of Carbon Accounting

Different approaches to carbon accounting are also possible based on a value chain approach. For example, E-liability System (Kaplan & Ramanna, 2021), Balance sheet reporting (Reichelstein, 2024), or Transactional Connectivity carbon accounting (Distler et al., 2024). Unlike the GHG Protocol, the focus is on the Scope 3 emissions that result from the value chain. The value chain of a real estate investment starts with the production of materials and continues with the construction and operation phases until demolition. An advantage of carbon accounting is the enhanced information on a building's carbon footprint, which can help in a strategy toward net-zero carbon (Penman, 2024). Based on value chains or life cycles, approaches are not without critique.

However, a significant limitation is the current lack of insight into downstream emissions, which could make the method less helpful in managing the carbon risk than suggested by Kaplan & Ramanna (Brander & Gatzweiler, 2024). No legislation requires the disclosure of carbon emissions in a transaction. Companies must report such information in their annual sustainability reports under the CSRD, enabling the value-chain approach to work more effectively in the future. An advantage of value chain reporting is its granularity, which allows for the same technique to be applied at various levels of detail.

2.4. Carbon Pricing

The following paragraph explores the monetisation of carbon accounting into portfolio management and investment decisions. This is commonly done using an (internal) carbon price to align with two important pricing mechanisms (Rabe, 2018). The first option is mitigating externalities by applying a tax (Pigou, 1924). A second option is carbon pricing based on a market principle (Coase, 1960).

The government uses both approaches to achieve its Paris-proof carbon reduction goals. An example is the recently introduced Emissions Trading System 2 (ETS 2) for buildings and road transport. This system will have mechanics similar to those of the existing ETS for large industry and energy companies, but it will be a separate market for emission certificates (Dutch Emissions Authority, 2023). ETS 2 is supposed to ensure a cost-efficient emission reduction and a level playing field for decarbonisation in real estate (European Commission, 2024). The ETS 2 works on the principle of 'cap and trade'. It limits the total amount of GHG emitted annually, reducing it over time. This upstream responsibility regulation incentivises energy suppliers to decarbonise their products, reducing the cost of compliance with the ETS 2. However, this inevitably increases fossil energy prices and forces tenants and owners to reduce energy demand. Analysis shows that only upstream regulation increases fossil energy prices, which is beneficial under limited coverage, as it also affects firms not directly affected by the policy instruments (Foramitti et al., 2021). The EU-ETS 2 is scheduled to start in 2025, focusing on monitoring and reporting carbon emissions, and is expected to be launched in 2027.

The impact of carbon pricing on reduction is questioned, as only specific sectors are affected, and the price per ton of carbon would be too low to be effective (Ball, 2018). Others argue that it is too early to assess the success of carbon pricing (Aldy & Stavins, 2012). However, the number of carbon pricing initiatives worldwide is increasing rapidly. According to the World Bank, pricing schemes have increased from 7% to 23% of global emissions over the past decade.

A recent report by the OECD shows significant progress of the ten leading countries between 2015 and 2028, reducing their carbon footprint, equivalent to a rising carbon price per ton (Hoeller et al., 2023). Demonstrating that ETS only makes sense if the cost per ton of carbon is high enough. Otherwise, it is cheaper to accept markdowns or pay taxes, which is particularly true for the real estate sector. A special report by the UN IPCC (IPCC, 2019) states that the amount spent to reduce a ton of emissions is higher in real estate than in every other sector. A higher price for a ton of carbon is essential to the real estate sector to incentivise the industry to reduce its carbon emissions. This makes it imperative for real estate investors to start accounting and reporting. It also emphasised the need for a uniform carbon accounting and pricing approach.

2.5. Internal Carbon Pricing

The transition from carbon accounting to decision-making on a corporate level is often facilitated by a carbon price. Many real estate organisations are preparing for carbon accounting and pricing by implementing an Internal Carbon Pricing (ICP) framework. Because it can be used as a strategic planning tool and help real estate investors transition to a low-carbon economy. The calculated virtual cash flows can impact the standing investments and decision to acquire new developments (Carbon Pricing Leadership Coalition, 2021). The drivers for using an ICP are systematically presented in the whitepaper of Möller et al. and can be divided into internal and external (Möller et al., 2022). The internal drivers can be subdivided into operational and strategic drivers. The most important internal operational drivers are the reallocation of capital and competitive advantage. Strategic drivers can be SDG alignment, ESG policy, and climate neutrality. Some examples of external drivers that can drive the use of an ICP include navigating GHG regulations and hedging against rising costs.

Following the two main approaches of trade and taxes, Gorbach classifies several ICP methods: carbon fees, shadow prices, and hybrid systems (Gorbach et al., 2022). These are based on the work of Ahluwalia, who defines these three different approaches. A carbon fee (1) strategy assigns a monetary value to the emissions produced by regular business operations. Although the funds would remain within the organisation, they could create a source of income to support the company's initiatives to achieve its goals for reducing greenhouse gas emissions. Other companies use a theoretical price, known as a shadow price (2), for risk assessment purposes when evaluating investments, testing assumptions, and informing business strategy in preparation for potential carbon restrictions, rather than an actual fee. The current or predicted cost of carbon regulations frequently determines shadow prices. A combination of both is also possible; companies use an internal fee as an instrument to reach their greenhouse gas reduction targets, while a shadow price serves as a guide in current investment decisions. This combination of methods is defined as hybrid carbon pricing (3).

Recent research by the Urban Land Institute shows that more real estate investors consider carbon pricing a significant attempt to decarbonise the built environment and play their part in tackling the climate crisis (Morrison & Phillips, 2023). However, it also acknowledges the challenge of a company-by-company approach and advocates for a wider adaptation. According to the ULI report, the real estate sector is a slow adopter; however, participants report an internal price for carbon of €45 per ton of carbon. ICP can help firms reduce emissions faster, especially capital-intensive firms, which can make investment decisions with a significant carbon impact (Byrd et al., 2020).

Carbon pricing is also a topic of discussion because monetising the emissions with a carbon price is based on the correct assumption. Furthermore, the time value of carbon is not considered. Time value is a concept in which carbon reductions now have more value than future reductions due to the time required to achieve them (Carbon Leadership Forum, 2017).

2.6. Internalising a Carbon Pricing Framework

Governments and the private sector are responsible for reducing and mitigating carbon emissions. While there are resources for implementing price instruments to address national-level damages from carbon emissions, companies and other institutions face limited resources. Addicot's framework outlines crucial decisions and trade-offs that organisations must consider when designing and implementing an internal carbon pricing program. It emphasises the various tools available for companies to create an internal carbon charge program that aligns with their specific needs. (Addicot et al., 2019). His research indicates that companies currently implementing internal carbon-pricing schemes are preparing for anticipated future regulations and, therefore, are externally driven.

The earlier-mentioned study by Gorbach (2022) provides an overview of barriers and motivators for incorporating an ICP, culminating in a flow chart for decision-makers. However, the study does not investigate different types of emissions, is not sector-specific, and has not been tested against practice (Gorbach et al., 2022). Carbon pricing can be beneficial, particularly for capital-intensive industries such as real estate. Companies using a carbon price have significantly different revenue levels. Results suggest that internal carbon pricing helps capital-intensive firms make an investment decision and lower their emissions, provided the carbon price is high enough (Byrd et al., 2020).

In the next section, an investment valuation based on a DCF is supplemented by three separate cash flows for different carbon emissions.

3. Method

3.1. DCF for a Sample Asset

The approach is used at the asset level to measure the effect of carbon pricing, considering an individual investment decision. A dilution effect is expected with the equal approach at the portfolio level. Assets will influence each other, with sustainable assets compensating for less sustainable assets in the portfolio and, as such, 'dilute' the overall non-sustainability of a portfolio. Furthermore, at the portfolio level, the value and size of an asset also play an essential role in its weight in the total portfolio. This creates undesirable effects, making it difficult to conduct a good impact analysis of carbon pricing.

As described, a commonly used model for incorporating carbon accounting into decision-making involves assigning a price per ton of carbon. In the following section, we consider a standard real estate investment calculation based on the DCF valuation model, which incorporates carbon pricing for three types of carbon emissions over the asset's lifetime.

In this example, a 12,500 square meter office in the Netherlands with an investment value of €62,500,000 is being leased for €2,812,500 per year over a 15-year term. The rent has an annual index of 2% (MSCI, 2025). Additional assumptions include a vacancy rate of 10% and maintenance costs equal to 15% of total rental income. The exit value of the asset is calculated by indexing the acquisition costs at T=0 with a 3% annual revenue growth rate (MSCI, 2025). Without a carbon price, the expected IRR is 5.79% in the base scenario.

3.2. Additional Carbon Flows

The DCF model includes three extra cash flows: Operational Carbon Costs (OCC), Embodied Carbon Costs (ECC), and Maintenance Carbon Costs (MCC). The OCC are based on the WEII Protocol of the Dutch Green Building Council (DGBC), a land- and sector-specific operational carbon emissions pathway (Van Bruggen et al., 2023). The ECC are based on another standard of the DGBC and limits embodied carbon for new constructions (Spitsbaard & Van Leeuwen, 2022). The MCC is set at 115 kg CO_2/m^2 based on a paper by Huang et al. (Huang et al., 2024). They analysed 72 studies on LCCE (Life Cycle Costing for Estimate) and found a median of 114.9 kg CO_2-eq per m^2 based on a lifespan of 50 years. The applied MCC is an average of the carbon emissions during the use stage (B1-B5) for maintenance, repair, renovation, and replacement, including transportation and equipment. In this sample, concrete, timber, and steel construction are represented. The table below presents all the aforementioned parameters. These maintenance carbon costs (kgCO2eq/m^2) are likely to decrease under legislative pressure, given the 2050 targets. However, this was not considered in the analyses; thus, the effect of MCC pricing may become smaller.

Table 1 Parameters for different sorts of carbon per year based on several sources. Authors' own work

Carbon flow	Unit	2025	2030	2035	2040	2045	2050
Operational Carbon (Module B6)	kWh/m^2/year	330	230	150	100	70	0
Embodied Carbon (Module A1-5)	KgCO_2-eq/m^2	204	158	122	95	73	56
Maintenance Carbon (Module B1-5)	kgCO_2-eq/m^2	115	115	115	115	115	115

Each flow of carbon emissions is monetised with a carbon price into the DCF. The carbon price varies from 0 to 5,000 Euro per ton of carbon and can be indexed yearly at 2.8% on the varied pricing. The index rate for the carbon price is based on the 10-year index of EU Carbon permits (Trading Economics, 2025).

3.3. Five Analysis

In the first analysis, only operational carbon during module B is incorporated using an internal carbon price. Subsequently, the embodied carbon from Module A is translated with an internal carbon price in the second analysis. The third analysis further expands the model by incorporating a carbon flow for maintenance. The last two analyses focus more on the indexation of the carbon price and the influence of lifespan on the IRR.

1. IRR with a carbon price for OCC (Module B6)
2. IRR with a carbon price for OCC and ECC (Module A and B6)
3. IRR with a carbon price for OCC, ECC, and MCC (Module A and B)
4. The influence of a carbon price index of 2.8%
5. The impact of a DCF duration varies between 15, 25, and 40 years.

A modest graph of each analysis is available, with the Carbon Price on the X-axis and the Internal Rate of Return (IRR) on the Y-axis. The title shows the analysis, and the legend indicates the assumptions made.

4. Results

4.1. Analysis 1 - IRR with a Carbon Price for OCC (Module B6)

In the first analysis (Figure 2), a cash flow for operational carbon is modelled with a carbon price between €0 and €5,000 per ton. The impact of this additional cash flow on operational carbon is presented in Figure

2. The effect on the IRR of the carbon price is shown for five different operational carbon footprints. The yearly carbon emission ranges from an average energy intensity of 330 kWh/m²/year to 0 kWh/m²/year. The operational carbon cash flow and the rental income start in T=1 after the initial investment costs in T=0. Hence, all graphs start at an IRR of 5.79% at T=0 and then differentiate from T=1 onwards.

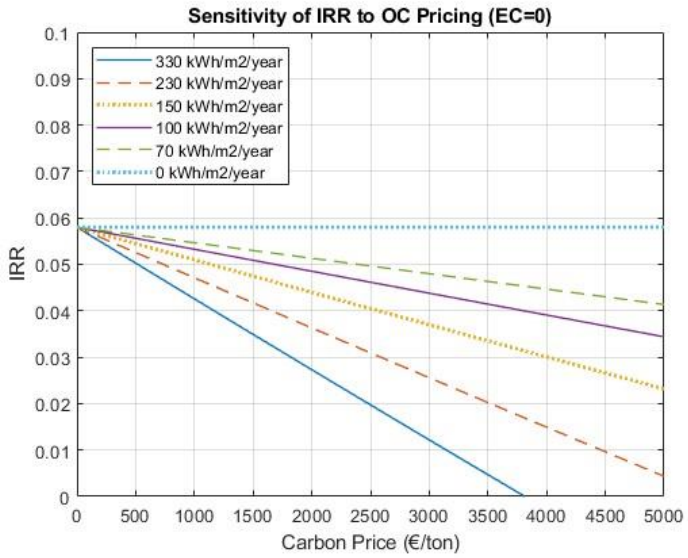

Figure 2 IRR per Carbon Price for Operational Carbon Costs. Authors' own work.

4.2. Analysis 2 - IRR with a Carbon Price for OCC (Module B6) and ECC (Module A)

The second analysis (Figure 3) includes a cash flow for embodied carbon emissions, ranging from €0 to € 5,000 per ton. In the second graph, the different embodied carbon intensities are modelled for an asset with a standard operational energy intensity of 70 kWh/m^2, which is considered nearly zero carbon intensity. In each analysis, embodied carbon varies in cash flow at T=0, so each graph starts with a different IRR. Because it is included only at T=0, the effect at lower Carbon Prices is small but spreads strongly towards € 5,000 per ton CO_2-eq.

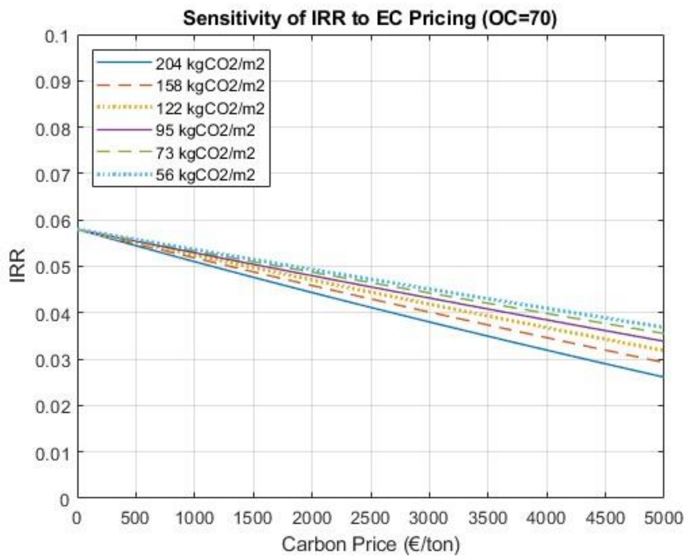

Figure 3 IRR per Carbon Price for Operational and Embodied Carbon Costs. Authors' own work.

4.3. Analysis 3 - IRR with a Carbon Price for OCC (Module B6), ECC (Module A), and MCC (Module B1-5)

In the third analysis (Figure 4), in addition to Operational Use, the emissions associated with daily maintenance and renovation (B1 to B5) are also included. The sample asset has an Embodied Carbon of 204 $kgCO_2$-eq per m^2 and an Operational Carbon of 70 $kgCO_2$-eq per m^2. For MCC, the 115 $kgCO_2/m^2$ over 50 years, based on a paper by Huang et al. (2024), is discounted to an annual cash flow. Maintenance carbon cost (MCC), though contributing modestly to annual cash flows, has a substantial cumulative impact over a building's lifecycle.

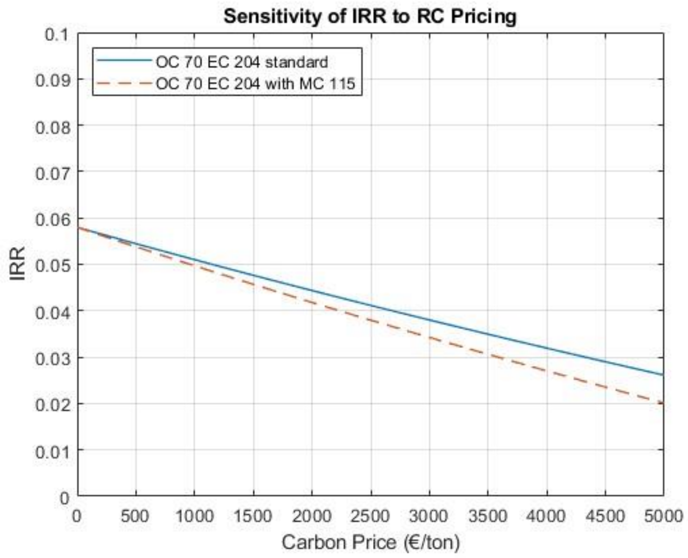

Figure 4 IRR per Carbon Price for Operational, Embodied and Maintenance Carbon Costs. Authors' own work.

4.4. Analysis 4 - The Influence of a Carbon Price Index on the IRR

Continuing with the example from the previous analysis, the carbon price is indexed at 2.8% per year over the total term. This carbon index is based on a 10-year index of EU Carbon permits. The graph (Figure 5) shows the base IRR for an asset (OC 70; EC 204, and MC 115) with and without indexing (2.8%). Logically, the index becomes more critical at higher carbon prices, which explains the divergence between the two lines.

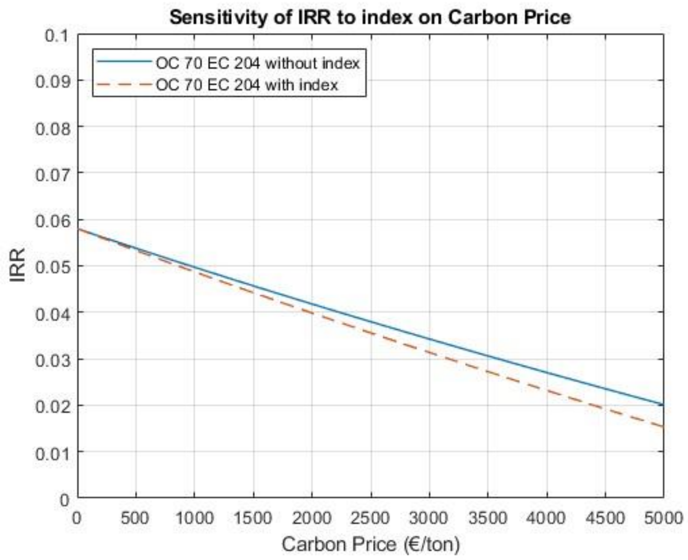

Figure 5 Influence of the Carbon Price Index on the IRR. Authors' own work.

4.5. Analysis 5 - The Impact of a DCF's Duration Varies Between 15, 25, and 40 years.

The last graph (Figure 6) presents the asset (OC 70; EC 204, and MC 115, indexed 2.8%) for 15, 25, and 40 years. Therefore, a difference is noticeable even at a carbon price of EUR 0. This difference increases as the carbon price increases. Both lines diverge because the revenue growth has a higher index (3%) than the sample's carbon price (2.8%).

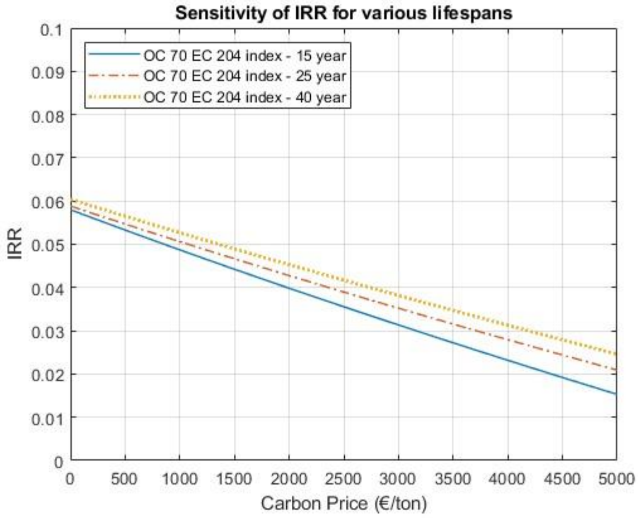

Figure 6 Impact of the duration of the DCF on the IRR for 15, 25, and 40 years. Authors' own work.

5. Discussion

The analyses result in several key insights into integrating carbon pricing within real estate investment decision-making processes.

When examining Operational Carbon Costs (OCC) in analysis 1, it is immediately noticeable that, for less energy-efficient assets carbon pricing has a major impact. For assets with higher energy consumption (230 to 330 kWh/m²/year), the internal rate of return (IRR) declines substantially, even turning negative at very high carbon prices (€5,000 per ton). Notably, the impact on investment decisions remains limited at the currently prevalent carbon pricing (€150 per ton). However, carbon pricing effectively excludes energy-inefficient assets if sufficiently high, as demonstrated by the significant IRR reduction from 5.79% to 4.96% at €2,500 per ton, even for energy-efficient assets (70 kWh/m²/year).

Including Embodied Carbon Costs (ECC) results in a relatively minor IRR impact due to its one-time nature during acquisition. At a carbon price of €2,500 per ton, the IRR difference between zero ECC and high ECC (204 kgCO2-eq/m²/year) assets is 84 bps (from 4.96% to 4.11%), suggesting carbon pricing for ECC might have limited effectiveness unless higher prices specifically target embodied carbon. Carbon pricing might not be the most effective tool for managing embodied carbon in investment decisions.

The impact of the operational carbon price on the IRR is more significant than the embodied carbon price. This is not surprising because the percentage of Operational Carbon over the Whole Life Cycle is more substantial and in line with earlier research (Adams et al., 2019). The embodied carbon cannot be compensated for or reduced during the lifespan. One solution could be to apply a higher carbon price for the ECC. In order to highlights the importance of embodied carbon in investment decisions.

Contrary to expectations, the Maintenance Carbon Costs (MCC) demonstrate noticeable IRR impacts, indicating their significance in investment valuations. At a carbon price of €2,500 per ton, including MCC, the IRR decreases by an additional 32 bps (from 4.11% to 3.79%). Given these findings, MCC deserves explicit consideration in investment decisions. However, the actual MCC might be lower initially and increase over time, suggesting the potential for asymmetric annual distributions not captured by the current evenly distributed model. The MCC will be lower in the first 15 years, affecting the IRR less than modelled in this analysis.

Indexing carbon prices annually (at 2.8%) effectively captures future increases in carbon avoidance costs, enhancing carbon pricing's relevance in decision-making. At high carbon pricing (€2,500 per ton), the IRR difference with indexing reaches 24bps (from 3.79% to 3.55%), reinforcing the value of incorporating indexing into models. However, caution is advised due to potential fluctuations in market-driven indices.

The analysis also highlights that longer durations in Discounted Cash Flow (DCF) calculations result in higher IRRs due to the cumulative positive impact of ongoing revenues relative to initial investments. Specifically, extending the duration from 15 to 40 years increases IRR from 3.55% to 4.17%, illustrating the temporal sensitivity of investment outcomes.

While this paper focuses primarily on new acquisitions without considering emission reductions from renovations, the approach is adaptable for evaluating renovation scenarios provided emission savings are adequately captured. Additionally, alternative sustainability strategies, such as using circular or biobased materials or lower-carbon construction materials like timber, could benefit from carbon pricing by reducing ECC and MCC, thereby positively impacting IRR.

Nevertheless, enhancing the effectiveness of carbon pricing in investment decisions requires more precise measurement and substantiation of carbon emissions, particularly for operational and embodied emissions at the point of acquisition. Given the range of assumptions involved, from carbon pricing to emission estimates, further methodological refinements are necessary before widespread practical implementation.

6. Conclusion and Recommendations

The real estate sector must transition towards a low-carbon economy. In current investment decisions, carbon emissions are insufficiently considered and may not contribute to a low-carbon portfolio aligned with the sector's target. Therefore, investors require a different approach to invest capital in projects that support this goal. The best way to achieve this goal is to adapt an existing tool, specifically a Discounted Cash Flow (DCF) model, which is often used in investment decisions.

Based on the DCF model, the following five key points regarding carbon pricing in real estate investment decisions were found:

1. A sufficiently high carbon price is necessary to meaningfully impact investment decisions, particularly to exclude energy-inefficient assets from investment portfolios. The operational carbon cost (OCC) has a significant impact on the internal rate of return (IRR), highlighting the potential of carbon pricing as an effective financial mechanism to steer capital toward energy-efficient real estate assets.
2. Embodied carbon cost (ECC) has a relatively minor influence on investment decisions compared to operational carbon. Given its limited impact on the IRR, carbon pricing for ECC alone may not substantially alter investment behaviour unless significantly higher prices for embodied carbon are adopted.
3. Maintenance carbon cost (MCC) notably impacts investment decisions and should be factored into appraisal models. Although its annual cash flow contribution is relatively small, its cumulative effect over a building's lifespan is significant, warranting consideration in investment calculations.
4. Furthermore, indexing carbon prices annually at a rate consistent with historical EU Carbon permit prices (2.8%) increases the effectiveness of carbon pricing mechanisms, reflecting the rising future cost of carbon emissions.
5. Additionally, longer durations in discounted cash flow (DCF) analyses enhance the IRR, as more extended holding periods increase cumulative positive cash flows relative to initial investments and negative cash flows from carbon costs.

For the most extensive analysis with a carbon price for EC, OC, and MC, which are indexed (2.8%) over 15 years, the IRR declines from 5.79% with a carbon price of €0 per ton towards 3.55% at a carbon price of €2,500 per ton. This represents an absolute difference of 2.24%, making it a practical approach to steer capital towards low-carbon investments.

Therefore, investors should apply a carbon price to affect investment decisions by excluding carbon-intensive assets from investment portfolios. Investors could align their capital with the sector's low-carbon goal by including monetised carbon emissions in an investment decision.

6.1. Framework for Investors

To facilitate the integration of carbon cost considerations into future investment decisions by institutional investors, a structured framework is proposed. This framework outlines five key decision points: (1) establish the internal carbon price, (2) determine of the scope (embodied, operational, and/or maintenance-related emissions), (3) define the investment horizon, (4) apply an appropriate index to adjust the carbon price over time, and (5) the incorporation of these elements into the cash flow analysis. Upon completion of these steps, the resulting internal rate of return (IRR) can be evaluated against the required IRR. This comparison serves as the basis for investment recommendations, which may support proceeding with the investment, suggest emission reduction measures, or advise against the investment altogether.

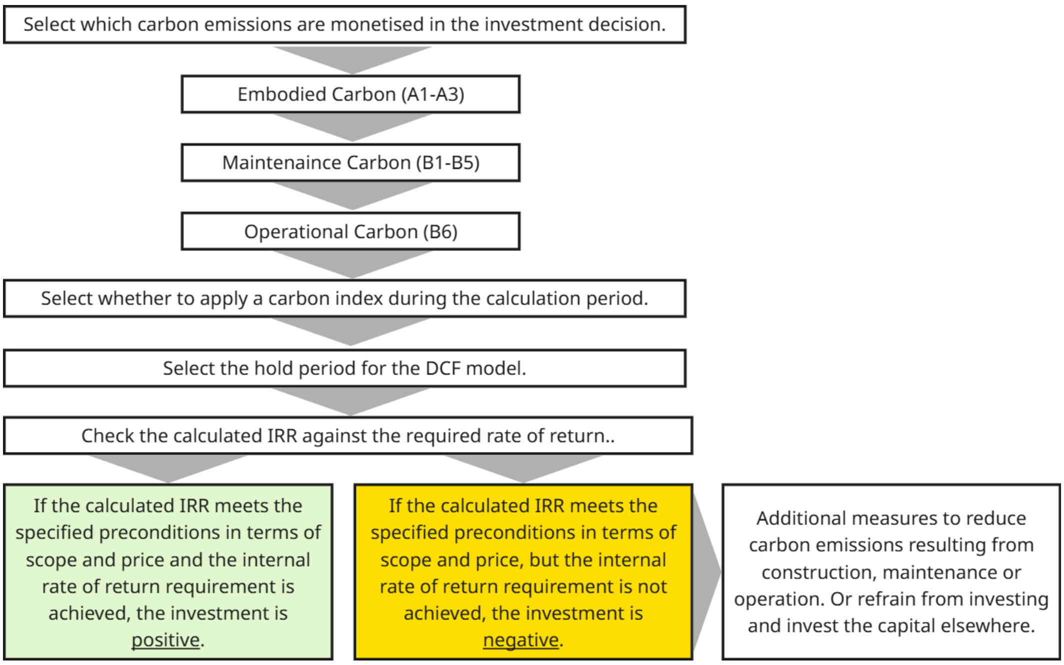

Figure 7 Framework for incorporating carbon pricing into financial decision-making. Authors' own work.

6.2. Limitations

The research has several limitations; the decision-making process of investors is reduced to the use of a DCF model, with a simplified risk perspective, and ignores investors' behaviour. The model has been tested using a simple office as a sample asset with basic assumptions; the outcome may be highly dependent on the asset's characteristics, sector, and location. The proposed approach does not address Module C: Demolition and Reuse, which can have a significant impact on the Whole Life Cycle but is often out of scope for institutional investors' decision-making processes.

6.3. Future Research

This paper focuses on new acquisitions and excludes reductions in operational emissions resulting from large-scale renovations. To advance this research, further analyses could quantify the trade-offs between embodied and operational carbon in renovation scenarios. Other sustainable strategies could also benefit from including carbon emissions in a DCF valuation method. For instance, circular or biobased materials used in the construction or maintenance phase result in a lower ECC and MCC, which has a favourable impact on the IRR. Another application could be evaluating the construction of a building with other, less carbon-intensive materials, such as timber. Advancing this research could involve examining the effectiveness of carbon pricing at the portfolio level, as well as incorporating different strategies for acquisition, renovation, and disposition.

The use of carbon pricing in investment decisions is promising; investors determine the level of the internal price. A follow-up study could therefore focus on the extent to which investors consider carbon in their investment decisions. There is likely a relationship between ambition and the level of the carbon price. In addition to ambition, the real estate sector or the country in which investments are made may also influence the level of the carbon price.

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Declarations

Competing interests The authors declare no competing interests.

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